

Method of monitoring the operationality of a flow cut-
off member and flow arresting system, for an
extracorporeal fluid circuit

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DESCRIPTION

10 The present invention relates to a method of monitoring the operationality of a flow cut-off member for an extracorporeal fluid circuit; the invention also relates to a flow arresting system for an extracorporeal fluid circuit.

15 In particular, the invention is of application in ensuring the correct functioning of a flow cut-off member operating on a blood return line to the patient in an extracorporeal circuit connected to a blood treatment appliance. The invention can also be applied
20 to carrying out an operation on the abovementioned flow cut-off member if it is found to be malfunctioning.

As is known, appliances for treating blood in an extracorporeal circuit, such as appliances for treating
25 renal insufficiency by haemodialysis, haemofiltration, or haemodiafiltration, plasmapheresis appliances, etc, use an extracorporeal circuit to carry the blood taken from a patient to a blood treatment unit. This unit normally consists of a containment body defining at
30 least one first chamber, for incoming blood, and at least one second chamber, designed to receive the unwanted particles and/or excess fluid present in the blood (or the plasma in the case of plasmapheresis). The two chambers are separated from each other by a
35 semipermeable membrane.

The first chamber of the treatment unit is then connected, downstream with respect to the direction of

movement of the blood, to a return branch or line carrying the blood back to the patient.

5 The terminal portion of the blood return line is normally fitted with an access member, such as a needle or other device, for connecting the extracorporeal circuit to the patient's vascular system.

10 Immediately upstream of this access member there is typically a flow interruption member, generally a clamp or pinch valve, capable of closing upon a length of tube of the blood return line to the patient.

15 In greater detail, the pinch valve has at least one movable portion designed to move between an open condition, in which flow is allowed along the tubing, and a closed condition, in which the movable part of the valve moves towards its fixed part, compressing the tube and therefore cutting off the flow of fluid
20 through the tube.

In the uses described above, the pinch valve acts as the final safety device, capable of cutting off the flow of blood to the patient immediately any
25 malfunction or any danger to the patient arises.

For this purpose, the pinch valve may be controlled by a monitoring unit communicating with sensors or transducers that pass to this monitoring unit signals
30 about potentially dangerous situations. For example, the monitoring unit may be linked to an air bubble detection unit active on the extracorporeal circuit upstream of the pinch valve: in the event of air bubbles large enough to create a situation of potential
35 danger to the patient, the monitoring unit closes the clamp, preventing the bubble from getting into the vascular system of the patient.

In order to be able to ensure operationality of the pinch valve, the latter is typically equipped with a position sensor for detecting when the movable part has reached a predetermined position (taken to correspond to closure of the tube) relative to the fixed part, upon which it sends a corresponding signal to the monitoring unit. In practice, the position sensor checks that, in flow cut-off conditions, the movable part of the clamp is separated from the lower fixed part by a predefined distance, approximately corresponding to the total thickness of the walls of the tube when compressed by the valve.

It is obvious that, given their nature, the position sensors connected to the cut-off systems described above are only able to supply an on-off type indication, i.e. they are only able to decide whether the movable part has reached a predetermined position of closure relative to the fixed part and possibly to recognize the presence or absence of a tube in the correct position inside the clamp.

Although widely used, the flow cut-off devices described briefly above have a number of limitations.

In the first place, devices with a pinch valve and position sensor cannot give information about how the valve carries out the transition to closure or relate the transition to closure of the valve to the manner in which the dangerous event is propagating towards the zone of access to the patient.

Still referring to a situation in which a detector device has reported the presence of an air bubble of excessive size in a predetermined zone of the extracorporeal circuit, the ideal solution would be to succeed in completely cutting off the flow of blood to the patient before the volume of blood present between the section containing the bubble and the patient

access point is completely exhausted. Clearly, if the clamp does not work fast enough, there is a risk of the dangerous event (in this case the air bubble) being transferred into the cardiovascular system of the patient. It should be stressed however that in reality there are numerous factors that can influence the operation of the safety clamp; to cite just a few: the theoretical speed of response of the chain from danger detecting sensor to CPU to valve, the speed of propagation of the dangerous event along the extracorporeal circuit, the actual efficiency of the valve, the mechanical properties of the length of tube subject to compression, etc.

It should also be noted that, in known systems, all that can be found out is whether or not the movable part or parts of the valve have reached a predetermined relative position unrelated to the actual geometry of the length of tube subject to compression; owing to manufacturing tolerances, the actual dimensions of the tube may obviously differ from one line to another, despite being of the same nominal dimensions. In practice, the thickness of the walls of the length of tube on which the valve acts varies between minimum and maximum values in a predetermined tolerance range. Therefore, although the closing action may be the same, the compression of the tube may be correct, excessive or too little, depending on the actual dimensions of the tube in question. It should be remembered here that the position sensor is designed to detect when the movable part of the clamp reaches a predetermined position; this position corresponds to a distance between the cooperating parts of the valves at which, theoretically, the flow through the tube would be cut off, assuming that the maximum wall thickness of the tube is in a tolerance range judged to be acceptable. This design decision avoids undesirable situations of false alarms but does not ensure that actual flow cut-off is monitored, particularly when the tube has walls

of the minimum thickness even if within a tolerance judged to be acceptable. The effects described above can be aggravated if the pinch valve is operated repeatedly on the same length of tube (as occurs for
5 example in single-needle treatments), causing deterioration to the material and/or permanent deformations thereof.

In the light of the above, it is a fundamental object
10 of the present invention to solve all of the problems described above that are typical of the prior art.

In particular, it is an object of the invention to provide a method capable of ensuring that a flow cut-
15 off member, for example a clamp, is operating correctly as it moves through its transition to closure.

In addition, it is an object of the invention to provide a novel method capable of interacting with the
20 flow cut-off member, so that the latter works reliably even in problematical working situations, such as malfunctions of the flow cut-off member, slow response of the various parts designed to activate the flow cut-off member, geometrical errors or tube positioning
25 errors, etc.

Lastly, it is an object of the invention to provide a flow arresting system, especially for extracorporeal blood-treatment appliances, that is capable of
30 implementing the abovementioned monitoring method.

These and other objects, which will become clearer in the course of the following description, are basically achieved with a method and system in accordance with
35 the appended claims.

Other features and advantages will become apparent in the course of a detailed description of a preferred,

but not exclusive embodiment of a method and system in accordance with the invention.

5 This description will be given below with reference to the appended figures, which are provided purely for guidance and are therefore not limiting, in which:

10 Fig. 1 relates to a general diagram of an extracorporeal blood-treatment appliance that implements the method and system in accordance with the invention; and

15 Fig. 2 illustrates schematically and in cross section a portion of tube on which a flow cut-off member acts, forming part of a flow arresting system according to the invention.

Referring to Fig. 1, an extracorporeal blood-treatment appliance is indicated as a whole by the number 1. The
20 appliance 1 may be, for example, a haemodialysis and/or haemofiltration and/or haemodiafiltration and/or ultrafiltration and/or plasmapheresis appliance. The appliance 1 comprises an extracorporeal circuit 2 designed to carry blood from a patient 3 to a blood-
25 treatment unit 4 and then return the blood, suitably treated, to a return zone where the blood is returned to the patient. For this purpose the extracorporeal circuit typically has a first access member 5a in fluid communication with a blood collecting line 5 leading to
30 an entry zone where the blood enters the treatment unit 4. The extracorporeal circuit also includes a blood return line 6 leading to a second access member 6a connecting to the patient's cardiovascular system for return of the blood to the patient. As an equivalent to
35 the structure described, a single access member may be connected alternately to the blood collecting line and then to the blood return line.

The blood treatment unit comprises a containment body defining at least two chambers 4a, 4b separated from each other by a semipermeable membrane 7. The first chamber 4a receives blood to be treated from the extracorporeal circuit briefly described above. In the case of haemodialysis, haemofiltration, ultrafiltration or haemodiafiltration treatments, the second chamber is designed to receive unwanted particles and/or excess liquid for removal from the patient's blood. In the case of plasmapheresis, the treatment unit 4 also includes a plasma filter.

The appliance 1 comprises a system 8 for arresting the flow of fluid, in this case blood, which will be described in detail below.

The system 8 acts on at least one flow cut-off member 9 operating on a length of deformable tubing 10 of the extracorporeal circuit; in particular, the flow cut-off member operates between an open condition, in which it allows the fluid to pass through, and at least one closed condition, in which it prevents the fluid passing along the said length of tube. In the example illustrated in Figure 1 the cut-off member is positioned on the return line 6 taking the blood back to the patient, close to and upstream of the second access member 6a. In more detail, it should be observed that the cut-off member comprises at least one movable portion 11 designed to move towards and away from a fixed portion 12. As illustrated in the example in Figure 2, the movable portion and the fixed portion together define a housing seat 13 in which the abovementioned length of tubing 10 sits. Because of the radial deformability of the length of tubing 10, the movement of the movable portion towards the fixed portion of the cut-off member causes progressive compression of the length of tubing, which therefore changes from an open condition, illustrated in Figure 2, to a closed condition in which the side walls of the

tube come together and cut off the flow of fluid. Movement of the movable member as described above is provided by an actuator 14 connected to the cut-off member 14. The actuator 14 may be of any type capable of bringing about a closing movement of the movable portion towards the fixed portion; in particular, a hydraulic, pneumatic, electric, electromagnetic, mechanical or any other type of actuator may be used. The actuator 14 acts under the control of a monitoring unit 15 connected to the said actuator.

The monitoring unit 15 of the system illustrated comprises a control unit 16, and means 17 for detecting a sequence of placings of the said movable portion in successive positions, sending corresponding signals to the said monitoring unit. In terms of construction, the monitoring unit comprises at least one microprocessor block 18, or CPU, and a memory 19 for the CPU. The detector means 17 meanwhile comprise one or more position sensors. In the example illustrated, there are two position sensors 20, 21 capable of detecting when the movable part 11 reaches two corresponding positions spaced apart from each other. The position sensors may for example be optical sights designed to send corresponding consent signals to the CPU 18 for the movement of the said movable portion 11.

The monitoring unit is also connected to a user interface 22 comprising an output device 23, such as a video display or the like, and an input device 24 comprising data reading means and/or a keyboard.

From the operating point of view, the system 8 behaves as described below. When a situation of danger is detected, the monitoring unit 15 sends a signal to the actuator to close the cut-off member as a safety function to prevent the event that has been judged to be dangerous from reaching the patient's cardiovascular system. In practice, by integrating the system 8 with

sensor means 25 designed to detect predetermined monitoring parameters (p_c) of correct operation of the said appliance, the system 8 acts whenever a situation judged to be dangerous is detected. Note that the
5 monitoring parameters may be, for example, the size of air bubbles that may be present in the blood, the temperature of the blood and/or the temperature of the dialysis liquid, the pH of the dialysis liquid, the pressure of the blood and/or of the dialysis liquid,
10 etc. In the example illustrated, the sensor means comprise an air bubble detector 26 connected to the extracorporeal circuit, on line 6.

Besides acting as a closure system, the system 8 checks
15 that the cut-off member is working properly when it closes: in this case the monitoring unit 15 implements a method of monitoring the cut-off member for correct operation. The system 8, or more precisely the monitoring unit 15, runs a check on the operationality
20 of the cut-off member whenever:

- a periodic preprogrammed automatic command (occurring every n minutes) autonomously activates the system 8, thus checking the cut-off member for correct operationality during closure;
- 25 - a preprogrammed automatic command autonomously activates the system 8 at the beginning of each treatment, thus checking the cut-off member for correct operationality during closure;
- a dangerous event has caused the cut-off member to
30 close; in practice, if the cut-off member is activated, its operationality is checked simultaneously; if the cut-off member does not operate as desired the monitoring unit can intervene directly to modify the action of the cut-off member.
- 35 In this last case, in practice, the monitoring unit both checks and controls the cut-off member.

Turning now to the detail of the functional description, whenever a manual command, an automatic

command or a particular event triggers its actuation, the monitoring unit 15 is capable of sending a signal to the said actuator 14 to move the movable portion (in the directions identified by the arrow 14a) of the cut-off member between a rest position, which corresponds to the open condition of the cut-off member and hence the passage of fluid through the said length of tubing, and a working condition, in which the movable portion acts to compress the portion of tube 10 to cut off the flow.

Notice that in the rest position the movable portion is typically at a distance from the surface 10a of the tube 10 and comes into contact with the latter during the movement towards the closed condition.

The monitoring unit 15 is also responsible for associating with the movable portion 11 at least one dynamic parameter p capable of providing an at least partial indication of the condition of motion of the movable portion during its movement from the rest position to the working position. It should be noted that a single dynamic parameter may be used, or a plurality of different dynamic parameters.

The monitoring unit 15 therefore determines a value V assumed by the said dynamic parameter or parameters when the movable part passes through a first position which the movable part can adopt during movement from the rest condition to the working condition. As an example, if the dynamic parameter in question is the speed of the movable part during the transition from the rest condition to the working condition, the monitoring unit will assess an average speed value assumed by the movable part in a neighbourhood of the said first position; alternatively, if the dynamic parameter is a time interval, the monitoring unit will determine the time taken by the movable part 11 to move for example from the rest position to the said first

position or, alternatively, the time interval taken by the movable part 11 to move from the first position to a second position at a distance from and subsequent to the first position.

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Once the monitoring unit has determined the actual value assumed by the predetermined dynamic parameter when the movable part is in a certain first position during its movement, the monitoring unit checks that
10 this value satisfies a predetermined criterion of acceptability. In other words, still referring by way of example to the case in which the parameter is speed, the monitoring unit compares the average speed of the movable portion at a predetermined first position with
15 a criterion of acceptability. This criterion of acceptability may be of predetermined type, such as a minimum speed capable of closing the cut-off member quickly enough. Alternatively, the criterion of acceptability may be calculated by the monitoring unit
20 as a function of other factors, for example as a function of:

- p_i , corresponding to or proportional to the pressure in the vicinity of the length of tube when the cut-off member is in the open condition;
- 25 - f_l , corresponding to the rate of flow of fluid through the length of tube when the cut-off member is in the open condition.

Returning to the description of the operating phases
30 initiated by the system 8, it should be observed that the first position in which the value assumed by the abovementioned dynamic parameter is determined is a position preferably intermediate between the rest position of the movable part and the working position
35 of the same movable part. In greater detail, the first position is intermediate between the ideal working position (complete closure of the tubing 10 with tube of exactly nominal dimensions) and a position of

initial contact between the movable portion and the outer surface of the length of tubing.

As has been mentioned earlier the dynamic parameter is
5 designed to describe a condition of motion of the movable portion.

In this regard, this parameter is selected from the group comprising the following dynamic parameters:

- 10 a) p1, corresponding to a time interval dT taken by the movable part to move between the first predetermined position and a second predetermined position at a distance from the said first position,
- b) p2, corresponding to a speed of the said movable
15 part at the said first position,
- c) p3, corresponding to an acceleration of the said movable part at the said first position,
- d) p4, corresponding to a function $F(p1)$ of the said parameter p1,
- 20 e) p5, corresponding to a function $F(p2)$ of the said parameter p2,
- f) p6, corresponding to a function $F(p3)$ of the said parameter p3, and
- g) p7, corresponding to a function of one or more of
25 the parameters p1, p2, p3.

To summarize, if the dynamic parameter p is linked to a time interval or to a function of a time interval, the monitoring unit calculates the value of the said
30 parameter p as the time dT (or as a function of the time dT) taken by the movable part to move from the first position to a second position at a distance from the first position. Once the time interval used by the movable portion to carry out a predetermined movement
35 between two positions has been calculated, this time interval is compared with the criterion of acceptability. Alternatively the time interval may be determined and, therefore, a function proportional to this time interval is calculated in order to then

compare it with a criterion of acceptability. If the dynamic parameter associated with the movable portion is the speed or a magnitude that is a function of the speed (kinetic energy, momentum or the like), the monitoring unit arranges for calculation of an average speed assumed by the movable portion in a neighbourhood of the said first position in order to then compare it with the said criterion of acceptability. Lastly, if the dynamic parameter is an acceleration or a function of the acceleration of the movable portion (resulting from the forces acting on the movable portion), the monitoring unit arranges for calculation of an average acceleration of the movable portion in a neighbourhood of the said position. Where the dynamic parameters consist of vectorial physical quantities, the important part is obviously calculating at least one component of these vectorial quantities in the direction followed by the movable part as it approaches the fixed part of the cut-off member.

Note that the parameter p or the parameters p_i can be determined by analogue sensors that output a continuous signal proportional to the instantaneous value of the parameter. In all cases, the monitoring unit arranges for a comparison between the analogue profile of the parameter p with a criterion of acceptability.

Note that the monitoring unit associates one, two or more parameters with the movable portion, each parameter being designed to give different dynamic information about the motion of the movable portion as it advances towards the fixed portion.

In one possible alternative, the monitoring unit is designed to carry out, for each dynamic parameter, a plurality of phases of determining values V_i assumed by that dynamic parameter at successive predetermined positions assumed by the movable part during its movement. Each value of the parameter in successive

positions is however determined essentially as described above.

By carefully selecting the dynamic parameters and the
5 criterion of acceptability, it is possible to work out
precisely how the movable portion of the cut-off member
is moving from the rest position towards the working
position. In other words it is possible to know the
speed of closure of the movable portion of the cut-off
10 member and be sure that the action of the cut-off
member is as it should be (the system is therefore
exercising a function of control of the closure action)
or at any rate be sure that a situation of incorrect
operationality is reported.

15 It should indeed be noted that if the value assumed by
the dynamic parameter or by a predetermined number of
dynamic parameters (if more than one is being used) is
not within a range of acceptability (or does not
20 satisfy a criterion of acceptability), the monitoring
unit can initiate an alarm signalling procedure and/or
a corrective procedure (control). Notice here that the
appliance 1 is provided with a user interface 22
equipped with a display by means of which the
25 monitoring unit can send an optical or acoustic signal
about the alarm condition. The monitoring unit can
also, depending on the situation, coordinate stoppage
of the treatment which the appliance 1 is performing
should the abovementioned alarm condition occur.

30 As mentioned, the monitoring unit is also capable of
activating a correction phase whereby the monitoring
unit intervenes on the actuator 14 to modify its action
on the movable portion of the cut-off member, in the
35 light of the difference between the value of the
dynamic parameter and a limit value judged to be
acceptable for that parameter. In practice, if a
reading of time, speed or acceleration throws up an
incorrect response by the cut-off member, e.g. the

movable part 11 is moving too slowly or excessive load is being transmitted to the length of tubing 10, the monitoring unit activates the actuator member in such a way as to increase or reduce the closing speed and/or force of the movable part. It will be clear that if the system is used for control, that is to say acting on the actuator to regulate the closing action of the cut-off member, then not only will there be a significant advantage of increased operational reliability, but also the possibility of damage to the tube and formation of cracks or detachments of parts of the tube is greatly reduced.

Alternatively, or in coordination with what is described above, the monitoring unit may act on means 27, such as a peristaltic pump, designed to set up a flow of liquid within the extracorporeal circuit, in such a way as to vary the rate of the said flow. In practice, if the movement of the movable portion has been found to be too slow, the actuator can be used to increase its speed, and the pump 27 connected to the extracorporeal circuit can be used simultaneously or alternatively to slow down the rate of flow of fluid through the circuit tubing. By this means, any dangerous event that is using the extracorporeal circuit as a means of propagation is clearly slowed down, allowing the cut-off member to close the circuit safely and cut off the flow towards the patient.